Study on Static Behaviour and Flow Characteristics of Magnetic Fluid in a Pipe(磁性流体の管内静及び流動特性に関する研究)

著者	Jessie Htwe
号	1055
発行年	1986
URL	http://hdl.handle.net/10097/9791

氏　　　　名	ジエスイ・トウエ Jessie Htwe
授 与 学 位	工　学　博　士
学位授与年月日	昭和 62 年 3 月 25 日
学位授与の根拠法規	学位規則第 5 条第 1 項
研究科，専攻の名称	東北大学大学院工学研究科 （博士課程）機械工学専攻
学 位 論 文 題 目	Study on Static Behaviour and Flow Characteristics of Magnetic Fluid in a Pipe （磁性流体の管内静及び流動特性に関する研究）
指 導 教 官	東北大学教授 神山 新一
論 文 審 査 委 員	東北大学教授 神山 新一　東北大学教授 小林 陵二 東北大学教授 橋本 弘之　東北大学助教授 中塚 勝人

論 文 内 容 要 旨

Chapter 1. INTRODUCTION

Magnetic fluids are a colloidal suspension of many fine particles of solid ferromagnetic material in a carrier liquid such as water, hydrocarbon, ester and fluorocarbon. To prevent a solidification of particles and keep a homogeneous dispersion, a surfactant which consists of long and flexible molecules(e.g., oleic acid) is attached to the particle's surface.

Since the success in production of magnetic fluids, technological interest in the magnetic fluids has grown rapidly and led to numerous exploratory device and several proven engineering applications. It is important to study the behaviour of magnetic fluids in a nonuniform magnetic field with the view point of the development of magnetic fluid devices such as seals, energy conversion systems, dampers and actuators. In the present study, therefore, the experimental and analytical studies have been carried out on the static behaviour and flow characteristics of magnetic fluid in a pipe under a nonuniform magnetic field.

Chapter 2. STATIC BEHAVIOUR OF MAGNETIC FLUID PLUG IN A NONUNIFORM MAGNETIC FIELD

In order to improve the performance of a magnetic fluid plug seal and to clarify the effect of fluid volume on the burst pressure and the seal failure against immiscible fluid, simple experimental study of the static vertical magnetic fluid plug is carried out. The experimental burst pressure is measured as a function of fluid volume for tubes with inner diameters of 2, 3.4 and 6 mm. The relations of the burst pressure and fluid plug length for various tube diameters are shown in Fig.1. The sketch of an apparatus for water pressure loading is also shown in the same figure. It is clear that the optimum volume of magnetic fluid exists in such a vertical magnetic fluid seal and the fluid plug can sustain higher pressure against air pressure loading than that for water loading. Also, higher burst pressure can be obtained in the cases of tubes with small diameters, which is supposedly due to the effect of surface tension.

Figure 2 shows the variations of the initial and final positions of the upper and lower surfaces of the magnetic fluid

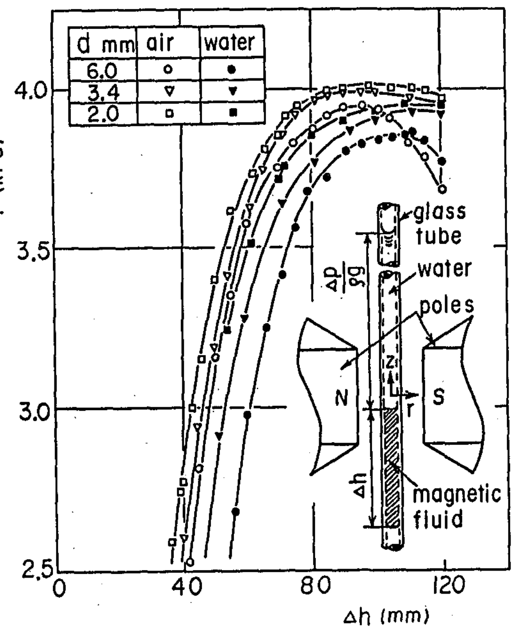

Fig. 1 Comparison between theoretical and experimental seal pressure

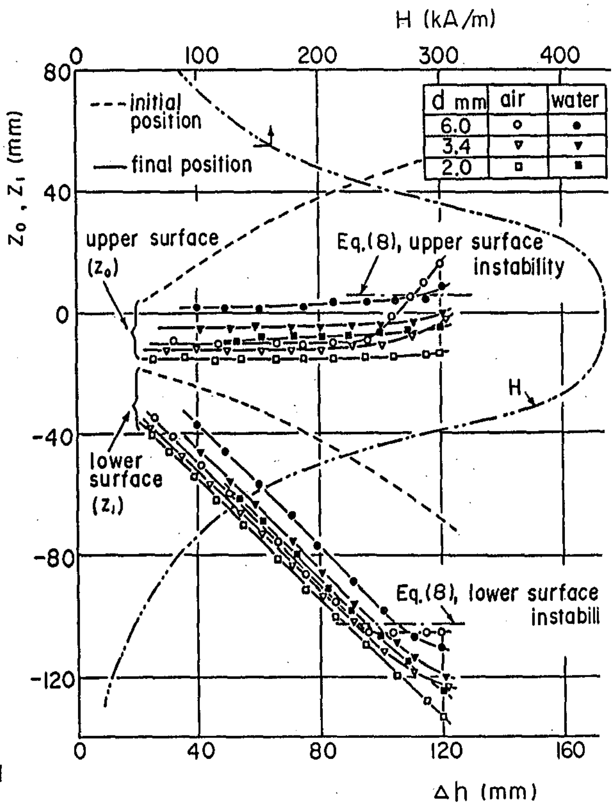

Fig. 2 Positions of upper and lower surfaces o fluid plug ($\Delta h = z_0 - z_1$)

plug with fluid length Δh in both cases of air and water pressure loading. It is clear that the initial position does not depend on the tube size, but the final position depends on the tube size as well as loading fluid. For water pressure loading, an upper surface instability occurs and causes the seal failure. The seal breaks when the upper surface approaches almost zero gradient field in the case of 6 mm diameter tube. On the other hand, the upper surface can reach the region of positive gradient field in the case of air pressure loading though the lower surface instability suppress further increase in the pressure difference near the optimum volume. However, the seal failure due to surface instability seems to be prevented partially by the effect of surface tension for small diameter tubes in both cases, so that higher burst pressure can be obtained. Thus, the interfacial instability plays an important role in establishing stable equilibria for an usable seal.

Chapter 3. BURST PRESSURE OF MAGNETIC FLUID PLUG BETWEEN INNER ROTATING AND OUTER STATIONARY CYLINDERS

To analyse the influence of rotating shaft speed and magnetic fluid volume on the burst pressure of a shaft seal, a basic analytical study is made taking into account the non-Newtonian properties of the magnetic fluid. Let us consider a small amount of magnetic fluid between inner rotating and outer stationary cylinders in a linear magnetic field distribution of $H(z)$ which corresponds to one step of the rotating magnetic fluid seal with rectangular tooth. At high rotating speed, the seal pressure decreases and the fluid free surface will deform due to the centrifugal force and cause the seal film to break particularly on the surface of an inner rotating shaft. To suppress the seal failure in high rotating speed, non-Newtonian viscoelastic magnetic fluid showing Weissenberg effect is considered.

Figure 3 shows the free surface boundaries of the magnetic fluid at various rotating shaft speed in both cases of Newtonian and non-Newtonian fluid behaviour with non-Newtonian parameter of $C_\beta = 0$ and 0.375, respectively. The use of non-Newtonian fluid behaviour is available for the retardation of seal failure on the surface of rotating inner cylinder.

Figure 4 shows the relation between seal pressure Δp versus magnetic fluid volume W. The optimum volume exists in such rotating magnetic fluid seal and higher seal pressure is obtained by use of non-Newtonian fluid properties.

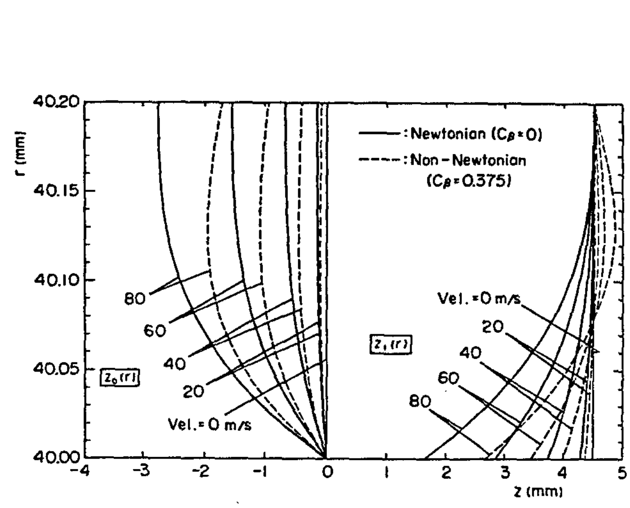

Fig. 3 Shape of free boundaries of seal layer

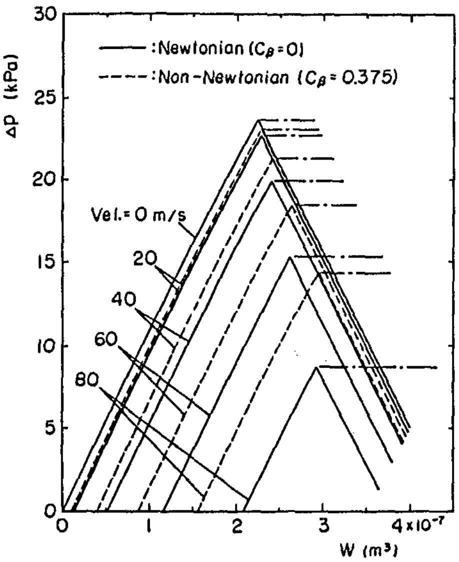

Fig. 4 Relation of $\triangle$p to fluid volume W

Chapter 4. STEADY FLOW CHARACTERISTICS OF MAGNETIC FLUID IN A PIPE

Detailed experimental studies are carried out to reveal the effect of the transverse magnetic field on the pipe flow resistance by measuring pressure distribution along the pipe axis in the uniform magnetic field including nonuniform field region at the inlet and oulet of the magnet as shown in Fig.5. The resistance coefficient of pipe flow is also obtained for venturi tubes of different configurations and the details of the test sections are also shown in the same figure.

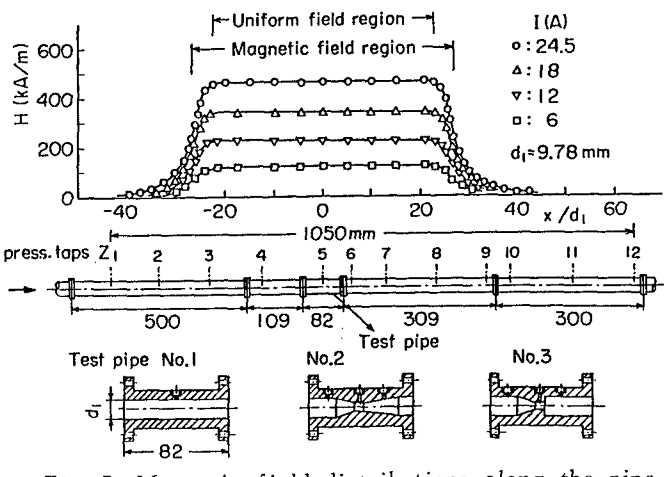

Fig. 5 Magnetic field distributions along the pipe axis and details of the test sections

Figure 6 shows the pressure distributions in the straight pipe(No.1) and two venturi tubes (No.2 and No.3) with and without magnetic field. The minimum pressure coefficient in the venturi tubes decreases due to the application of magnetic field. However, the flow resistance in the venturi tubes is much influenced by the pressure drop at the inlet and outlet portions of the magnet which is similar to that in the straight pipe. These results suggest that the losses in the nonuniform field are induced by the redistribution and some agglomerations of the solid particles under a strong magnetic field gradient. Also, the magnetic force acting on the particles is for the flow at the inlet and against it at the outlet of the magnet. It plays an important role in such pressure drop.

The experimental study is also made for flow through long orifices No.4 and No.5 with annular permanent magnet of different field distributions but same maximum strength installed around a throat portion. The comparison of the obtained pressure losses is as shown in Fig.7. Thus, the pressure drop depends not only on the field strength, but also on the field distribution. In the range of low Reynolds numbers, the pressure loss is influenced by the measuring time. This time effect on a pressure drop is supposedly caused by the increase of the magnetic particles concentration within the magnetic field region, since large magnetic field gradient of the permanent magnet brings to break the uniform dispersion of particles.

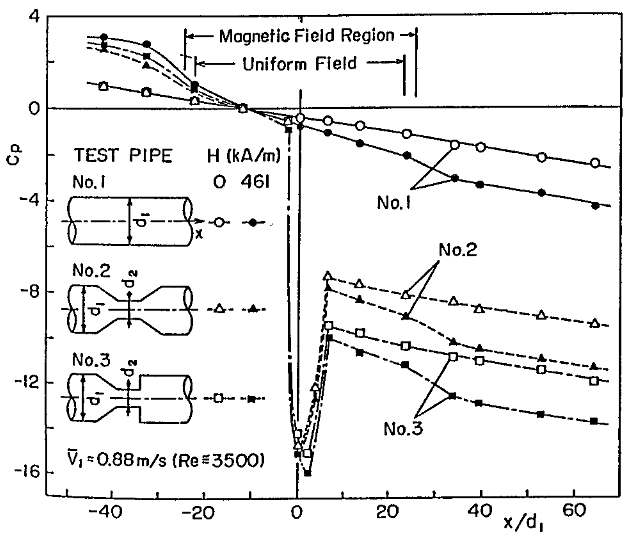

Fig. 6 The Cp distributions for straight pipe and venturi tubes

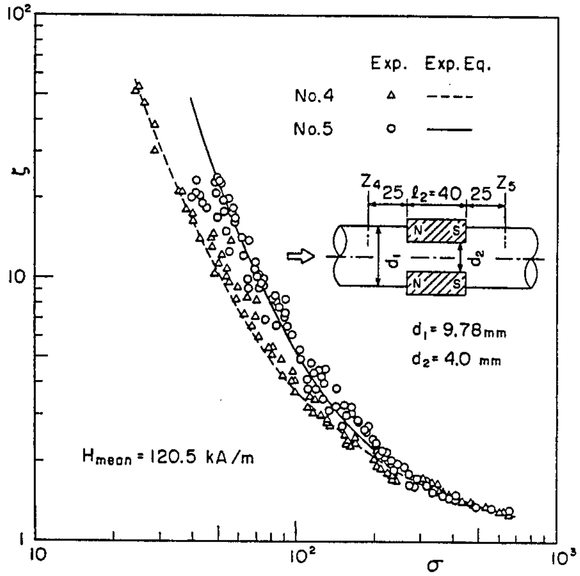

Fig. 7 Comparison of loss coefficient ζ between test pipes No. 4 and No. 5

Chapter 5. OSCILLATORY MOTION OF MAGNETIC FLUID PLUG IN A PIPE

The basic theoretical and experimental studies are made on the behaviour of a magnetic fluid plug oscillating in the straight pipe and U-tube with an exciting periodic magnetic field as a simple example of the magnetic fluid plug actuators.

The magnetic fluid plug is held by the intense of the nonuniform magnetic field distribution, then, an exciting periodic magnetic field is applied to the system. According to the exciting field, the fluid plug vibrates in the pipe.

The damping force of the system corresponds to the friction force on the fluid body vibrating in a pipe. Since there has no experimental study on the effect of magnetic field on pipe friction coefficient with oscillating motion, the friction coefficient is assumed to be constant as $\lambda = C/64$. In the absence of magnetic field, C is taken as 64. In the magnetic field, $C=64*C'$ is assumed since it is influenced by the applied field. Therefore, the correction factor C' to the pipe friction in a nonuniform magnetic field region is estimated from the experimental damping factor in the present study.

With an assumption that the pipe friction coefficient in a magnetic field with oscillating motion is constant, theoretical amplitude of vibration shows good agreement with experimental results as shown in Fig.8. Figure 9 shows the increase of maximum amplitude of vibration with fluid plug length within experimental range in the case of straight pipe. However, the maximum fluid length is restricted by an effective field region which also

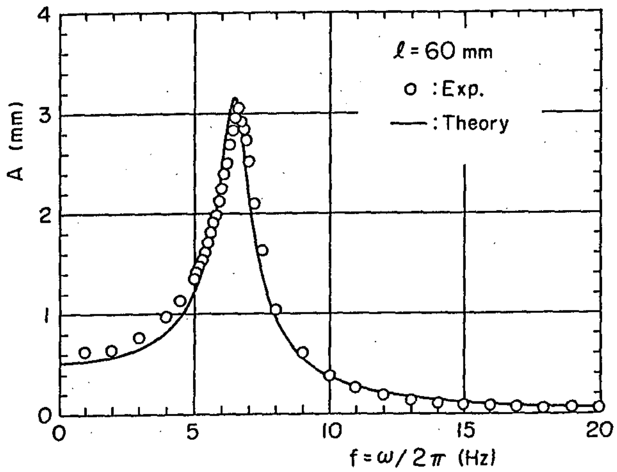

Fig. 8 Comparison between theoretical and experimental amplitudes

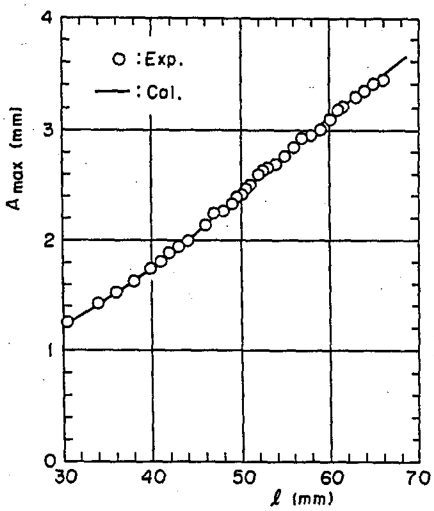

Fig. 9 Relation of maximum amplitude to fluid plug length

restricted the maximum amplitude of vibration. In the case of U-tube, the maximum amplitude depends on both the fluid plug length and position of the upper surface as shown in Fig.10. However, the initial position of the fluid upper surface and minimum plug length are also restricted by the maximum field strength. The resonance frequency decreases with the increasing plug length in both cases of straight pipe and U-tube.

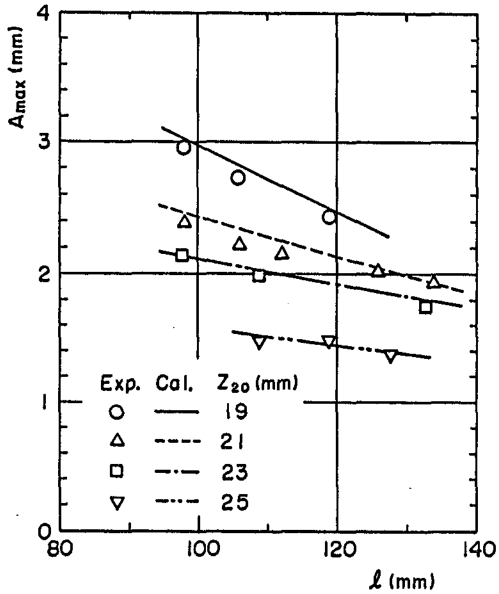

Fig. 10 Effect of upper surface position on maximum amplitude

Chapter 6. CONCLUSION

The results obtained in the present study can be summarized as follows:

(1) In a vertical magnetic fluid plug, seal pressure depends mainly on the fluid volume and partly on the tube size and loading fluid. Also, interfacial instability plays an important role in the seal failure mechanism.

(2) The use of non-Newtonian fluid having the Weissenberg effect is effective to suppress the seal failure at high rotating shaft speed.

(3) In the study of flow in the magnetic field, large pressure drop occurs in the nonuniform magnetic field region at the inlet and outlet of a magnet irrespective of pipe configuration in low Reynolds numbers. Pressure loss in long orifice having annular permanent magnet around the throat is influenced not only by the field strength but also by the field distribution.

(4) In the study of oscillating motion of magnetic fluid plug, the maximum amplitude of vibration increases almost linearly with fluid plug length in the case of straight pipe and on the other hand, in the case of U-tube it decreases with the increasing plug length.

(5) Considering the correction factor to pipe friction coefficient in a magnetic field, theoretical analysis shows good agreement with experimental results in the oscillation of magnetic fluid plug.

審 査 結 果 の 要 旨

強い磁性と流体としての挙動を示す磁性流体が開発され，その特性をいかした幅広い応用面の開発が活発化している。しかしながら，応用開発の基礎となる非一様磁界中での磁性流体の基本特性については，現象の複雑さのために，まだ十分に解明されているとはいえない。

本論文は，磁性流体を用いた各種応用機器開発のための基礎研究として，非一様磁界中の管内流れの問題および管内プラグの諸特性を理論的ならびに実験的に解明したもので，全編6章よりなる。

第1章は緒論である。

第2章では，磁性流体管シールの耐圧特性に着目し，垂直に立てた管内の磁性流体プラグの耐圧に及ぼす最大磁界強さ，磁性流体の体積，管径，負荷として加える流体の種類の影響を実験的に明らかにしている。また，垂直管シールの場合には，非一様磁界中での界面の不安定性がプラグの破断開始に重要な役割をはたすことを明らかにしている。これは有用な知見である。

第3章では，磁性流体軸シールの耐圧に及ぼす軸回転の影響を理論的に考察している。高速回転下でのシール界面の破断を防ぐためには，ワイゼンベルグ効果を示す非ニュートン磁性流体の使用が有効であることを提案している。これは実用的にも有用な成果である。

第4章では，非一様磁界中の管内定常流れの問題をとりあげ，管軸に沿う圧力分布の詳細な測定結果から，磁界勾配の大きな箇所で異常な圧力損失が生じること，また管内流れの圧力損失は磁界の最大強さのみならず磁界分布の形状にも強く依存することを明らかにしている。これらの成果は磁性流体を用いた流動制御装置の開発に新しい設計指針を与えるものとして高く評価される。

第5章では，変動磁界により管内流体プラグに往復動を与えた場合の動特性の理論解析を行い，その妥当性を実験的に確証している。これは磁性流体アクチュエータの応用に際しての貴重な基礎資料を提供するものである。

第6章は結論である。

以上要するに本論文は，非一様磁界の作用する円管内の磁性流体の静および流動特性を理論的ならびに実験的に究明し，磁性流体を用いた各種応用機器開発のための基本特性を明らかにしたもので，磁性流体工学の進展に寄与するところが少なくない。

よって，本論文は工学博士の学位論文として合格と認める。